Integrating Human-Centricity, Sustainability, and Resilience in Digital Twin Models for Industry 5.0 : A Multi-Objective Optimization Approach

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Résumé : *This paper presents the InduDesc framework, an innovative digital twin model within the CupCarbon software, designed for the advanced needs of Industry 5.0. It integrates human-centred ergonomics, sustainability and resilience into the Flexible Job Shop Scheduling Problem (FJSP), traditionally an NP-hard challenge. By minimising operating times and balancing machine utilisation with ergonomic and sustainability considerations, the framework provides a dynamic workload management tool based on real-time 'fatigue' metrics. Using a tabu search algorithm, InduDesc generates a Pareto frontier to help decision makers identify strategies that efficiently align with the integrated goals of Industry 5.0.*

Mots-clés : *Multi-Objective Optimization ; Ergonomics ; Digital Twin ; Industry 5.0 ; Flexible Scheduling Jobshop*

1 Introduction and Problem Description

Industry 5.0 is a major transformation that combines sophisticated technology with a strong emphasis on humanity, sustainability and resilience. Digital twin technology, which originated from NASA, is crucial to this transformation as it helps to create a collaborative environment between humans and machines [1]. It highlights the need to optimise engineering and logistics with multiple objectives, focusing on achieving a balance between conflicting goals such as efficiency, sustainability and ergonomic factors. Human factors engineering, also known as ergonomics, is essential to Industry 5.0 as it uses psychological and physiological principles to improve communication between people and industrial systems. This method ensures that technological advances support human well-being by creating a sustainable and employee-friendly environment [4].

Consequently, the Flexible Job Shop Scheduling Problem (FJSP) adapts to tackle the tough tasks of Industry 5.0. The FJSP is a tricky, typically NP-hard problem. It requires compatible machines to handle multiple jobs with a focus on efficiency, resilience, and human centricity [3]. Our model extends the typical optimisation objectives and incorporates these aspects into the FJSP. We aim to minimise the makespan (f_1), the total machine processing time (f_2), and to ensure balanced machine utilisation (f_3). In addition, the focus is on reducing the ergonomic burden on workers (f_4), increasing the sustainability of the manufacturing process (f_5) and improving the overall resilience of the system (f_6). The proposed digital twin model, based on FJSP, is adapted to a human-centred, sustainable and resilient industrial framework. It uses guided metaheuristic algorithms that are adaptable to the preferences of the decision makers, allowing the simulation and generation of efficient solutions in the complex milieu of Industry 5.0.

2 Framework Solution Overview

We propose the InduDesc framework within the CupCarbon software [2] as a digital twin tailored for Industry 5.0, depicting a network with nodes representing human operators and machines, connected by red lines illustrating workflows and communication paths. The framework monitors 'fatigue' to adjust workload ergonomically, optimises sustainability by reducing machine operating times, and adapts to worker fatigue to increase resilience. Our framework uses a post-simulation tabu search algorithm to synthesise these objectives into a Pareto frontier, providing decision-makers with optimal solutions that balance efficiency, worker well-being and environmental sustainability, which is crucial for strategic planning in Industry 5.0.
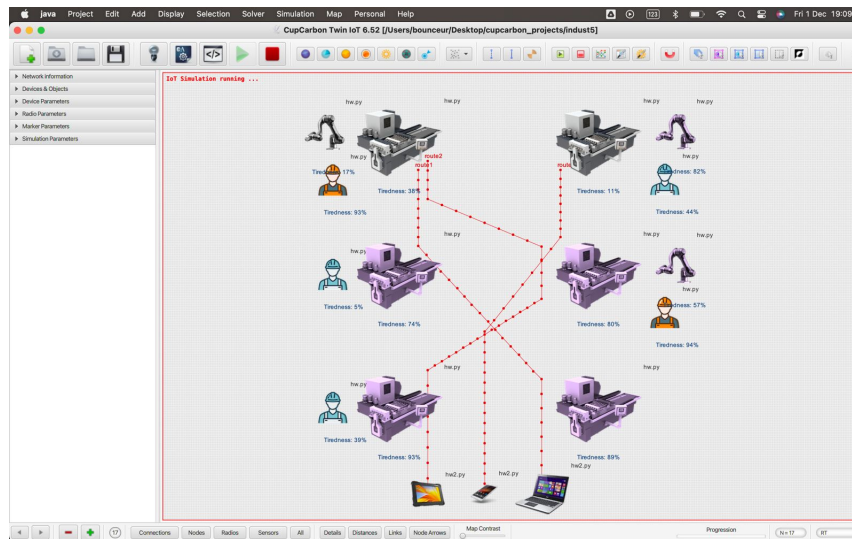

FIG. 1 – Visualizing Ergonomic Workload Management in Industry 5.0

Figure 1, shows a simulation interface of the InduDesc framework in CupCarbon software, depicting an Industry 5.0 digital twin network with machine and human operator nodes, where each node displays real-time 'Tiredness' levels for ergonomic workload management. You can watch the video here : https ://youtu.be/XKrnQGmyubY

3 Conclusion

The InduDesc framework marks a pivotal step in industrial innovation, skilfully combining the efficiencies of digital twin technology with the core principles of Industry 5.0. Its focus on real-time ergonomic assessment in manufacturing demonstrates a commitment to improving both productivity and worker well-being. This paper concludes that such integration is not only feasible, but essential for the resilient and sustainable advancement of modern industrial practices.

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